경제학석사학위논문

Analysis of Green Finance :

Funding for Investment Projects under Externalities

녹색금융 분석 :

외부성 존재 시 금융자본 배분 문제에 관하여

2013년 8월

서울대학교 대학원

경제학부 경제학 전공

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이 논문을 경제학석사 학위논문으로 제출함.

2013년 4월

서울대학교 대학원

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정현이의 경제학석사 학위논문을 인준함.

2013년 6월

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Abstract

Analysis of Green Finance
: Funding for Investment Projects under Externalities

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Utilizing a simple economic model, this paper analyzes why many firms that have new investment projects such as *'green'* technology or product often fail to finance from the financial market and lose opportunity to start up in the market. In a sense that finance plays positive roles in economic activities, this paper focuses mainly on the roles that finance plays in '*Green Growth*' which is briefly defined as achieving higher output with less pollution at the same time.

In this paper, we take the existence of externalities and asymmetric information problem between a bank and firms with *'green'* investment projects as important factors explaining why many *'green'* projects fail to be financed in the market. By using the economic model, we derive the socially optimum number of both conventional and '*green'* investment projects. The theoretical result shows that under the private choice, there are over-investment for non-environmentally friendly projects and under-investment for *'green'* projects compared to the socially optimum level. It implies that higher return and less pollution can be achieved eventually contributing to *'Green Growth'*, when banks consider the externalities when they allocate funds to each investment projects. Nevertheless, as one of the private agents, they do not have enough economic incentive to do so. That is why *'green'* investment projects often fail to start up in the market.

While showing mathematically that it yields higher output and less pollution when banks allocate funds considering externalities, this paper discusses several policy methods to induce these private agents to fully internalize the externalities and simultaneously emphasizes the roles finance plays in *'Green Growth'*. In this regard, imposing taxes and subsidies depending on the type of the investment project to either side of a bank or firm is such example. Additionally, alleviating the asymmetric information problem such as decreasing the *'verification cost'* that a bank has to pay to detect *'green'* industry is possible.

***Keywords**: Green Finance, Investment under Externalities, Environmental Pollution, Market Failure*

***Student Number** : 2011-23172*

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1 Introduction

This paper analyzes the role of the financial sector for '*Green Growth'* theoretically and discusses some policy implications for *'Green Finance'*. By using a simple mathematical model, this paper explains why many firms with *'green'* technology often fail to finance from the financial market and lose opportunity to start up in the market.

Noh (2011) defines *'Green Finance'* as following; a financial activity which pursues the development of financial industry, environmental improvement and economic growth at the same time. In other words, *'Green Finance'* is the finance that support the *'Green Growth'*[1] as well as preventing the environmental damage. Noh (2011) analyzes that '*green*'[2] industry has a characteristic of venture projects which are usually characterized to have high-risk high-return. Because of this reason, banks do not find it attractive to finance for *'green'* investment projects under the private choice problem. Often it has been only considered as socially responsible behavior to fund these kind of investment projects.

As I reviewed the literatures about *'Green Finance'*, I found out that there have been some studies regarding this subject, where most of these focusing on the practical issues such as financial products for *'Green Finance'* or explanations of policy finance for *'Green Growth'*. Koo (2010), Jeong (2012) and Noh (2011)

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[1] (Lee, 2010) *'Green Growth'* refers to a set of strategies that aims for continued economic growth and environmental progress both at the same time.

[2] (Lee, 2010) *'Green'* refers to activities that would reduce the per capita pollution if narrowly defined, or activities that would result in net addition to the environmental capital if broadly defined.

all commonly assert the appropriateness of the role of the finance in '*Green Growth'*. In fact, in many countries, financing for *'green'* investment projects has been supported by the policy finance such as subsidy. It has been difficult to draw private sector's participation as most green investment projects have high risk and uncertainties despite their appropriateness and high return when they succeed. Noh (2011) emphasizes that it is important to draw private financial sector's participation to finance *'green'* industry as there should be constraints at some point to depend only on government's subsidy. Koo (2010) points out that the government should take a role in supporting '*green*' industry using policy financing at the initial level of *'Green Finance'*, but in the long run the financial market itself should be able to finance green industry with market-oriented procedure. Koo(2010) also emphasizes that continued support of government towards '*Green Finance'* is unavoidable but it should stimulate private finance market to participate in the long run once it succeed to create efficient market for '*Green Finance'*.

The motivation for this paper is to approach these issues with economic theory model. More than emphasizing the role of '*Green Finance'* like in previous studies have done, this paper uses an economic model[3] to show mathematically to ascertain these findings. The model explicitly shows why firms with green investment projects often fail to get financed from the private financial sector. Then the model compares the private choice with the socially optimum level of investment on '*green'* industry.

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[3] Our theoretical model is inspired by Lee (2009) and Stiglitz (1975)

At last, we discuss some optimal financial policies to correct the under-investment for green investment projects and over-investment for non-environmentally friendly investment projects. These policies aim to induce private agents to fully internalize externalities they are creating and allow green investment project be financed at the socially optimum level. By these procedures, we emphasize the importance of role of finance towards '*Green Growth'*. Like in this paper, many economists have been interested in the roles that finance plays in economic activities (Lee, 1999). Schumpeter (1912) had emphasized the positive roles finance in fostering technological progress. Hicks (1969) emphasized the positive roles finance played in industrialization. Levine (1997) reviews recent approaches to the issue emphasizing the roles finance plays in economic development.

The remaining of this paper proceeds as follows. Following section 2 contains the economic model and equilibrium analysis. In Section 3, I will discuss implications and possible policy methods from the derived results and the further discussions for policy and the conclusion will follow in the last section.

2 Funding for Investment Projects under Externalities : An Economic Model

2.1 Model Setup

Consider a situation where N potential investors (firms) have one investment project each, where N is a very large number. All investment projects regardless of their type, require capital commitment of K, and each firms have only w as their own capital, which means they must borrow $K-w$. Indeed, w should be less than K and it is used as collateral, which is taken by the bank if the project do not succeed. We assume that there are only two outcomes for each project: a success or a failure.

2.1.1 Firms

Among N potential investors, I assume that there exist two types of firms; *type 1 firm* has an investment project with higher probability of success but lower return with some negative externality throughout the investment process compared to t*he type 2 firm*. p_1 is the success probability of *the type 1 firm'*s project, yielding S_1 as a return. *The type 1 firm* can be considered as the conventional industry firm which generates pollution or negative externality. We assume that this negative externality incurs once the investment is undertaken, regardless of whether the project succeed or not. On the other hand*, the type 2 firm*'s investment project has lower probability of success but much higher return when the project succeed and also it poses positive externality once it succeeds. The success probability of *type 2 firm's* project is p_2, and the return in this case is S_2. Additionally, we assume $p_1S_1 < p_2S_2$ although $p_1 > p_2$ and $S_1 < S_2$. Indeed, the probability of success and is less than 1 ($0 < p_1 < 1$ and $0 < p_2 < 1$).

Let the borrowing-lending rate R_1 and R_2 for the rate that each *type 1 firm* and *type 2 firm* faces respectively. We simply assumed that both types of firms would be financed with different borrowing-lending rate in the market since the risk that banks face with is different. Considering the factors affecting the riskiness, the interest rate would be determined in the market. Also, for simplicity, we assume that every investors, regardless of their type, have an opportunity cost of R^* on their own capital. R^* is taken as exogenously given parameter. Hence the expected profit function for each type of investors would be as follows:

Type 1 firm : (1) $E\pi_{f1} = p_1 S_1 - p_1 R_1 (K - w) - (1 - p_1) w$

Type 2 firm : (2) $E\pi_{f2} = p_2 S_2 - p_2 R_2 (K - w) - (1 - p_2) w$

2.1.2 Bank

A typical bank in our model will decide the number of each investment projects it would fund. Let n_1 and n_2 be the number of each project a bank is willing to fund to *the type 1 firm* and *the type 2 firm* respectively. Then the total amount of funds that a bank lends out would be $(n_1 + n_2)(K - w)$. For simplicity, we assume that there is no bound in an amount that a bank can lend out, which means $(n_1 + n_2)(K - w) \le N(K - w)$, where N is very large and indefinite number. In other words, there is no constraint in the amount of capital that banks can mobilize. The fact that we assume a typical bank and assume as if there are just one bank in the economy implies that the financial sector is assumed as competitive market for simplicity. Although it may be strict assumption, this is to focus on the financial sector's behavior of allocating financial capital to the investment projects.

When the investment project succeeds, the lending bank will get $R_1 n_1 (K - w)$ from *type 1 firms* and $R_2 n_2 (K - w)$ from *type 2 firms*. When the investment project fails, on the other hand, the bank can only get the collateral $n_1 w$ from *type 1 firms* and $n_2 w$ from *type 2 firms* respectively.

Also, note that banks mobilize the necessary funds by paying R^* on $(n_1 + n_2)(K - w)$. In addition, banks have to incur '*intermediation cost*' in the process of allocating funds to each type of firms. To allow for a unique equilibrium, we assume this cost is in the form of strictly convex and strictly increasing function of the volume of lending. We take $\frac{1}{2}[n_1(K - w)]^2 + \frac{1}{2}[n_2(K - w)]^2$ as a bank's '*intermediation cost'* function.

Moreover, in this paper, I assume that a typical bank has to pay some additional cost in order to verify *type 2 project* which has higher expected return despite higher risk than *type 1 project*. Such existence of the verification cost can be also rationalized in a sense that environmentally friendly project such as renewable energy projects are mostly new in the market than the conventional industry which incur pollutions as negative externality. In other words, since financial sector do not have much information on *type 2 firms,* additional cost to distinguish these firms would be needed for banks; *information asymmetry problem* exists in the market. We define such information asymmetry between a bank and the *type 2 firm* in the form of '*verification cost*', denoted by 'c'. It should be a dilemma for the lender in a sense that it has a possibility of getting higher return when allocating funds to *type 2 firm,* whereas it must pay off some additional cost for verifying this type of this firm. Thus a typical bank's expected profit function can be written as follows:

(3) $$E\pi_B = n_1[p_1(K-w)R_1 + (1-p_1)w] + n_2[p_2(K-w)R_2 + (1-p_2)w]$$

$$-\frac{1}{2}[n_1(K-w)]^2 - \frac{1}{2}[n_2(K-w)]^2 - n_1(K-w)R^* - n_2(K-w)R^* - cn_2$$

First two terms represent the expected return when allocating funds to each type of firms, and rest of the terms represent the total '*intermediation cost'*, the total opportunity cost and the '*verification cost'* respectively.

2.1.3 Externalities

As mentioned above, one of the critical features that distinguishes the type of a firm is that their investment projects have different kind of externality regarding the pollution. Every *type 1 firm* which succeed in borrowing from the bank; n_1 firms generate certain degree of pollution ' g ', thus generating pollution of $n_1 g$ in total.

We define the social pollution level G as following:

(4) $$G = n_1\,[g - \beta(\frac{p_2 n_2}{p_1 n_1})g] = n_1\,[1 - \beta(\frac{p_2 n_2}{p_1 n_1})]g \quad , \quad \left(\left(\frac{p_1}{p_2}\right)\frac{p_1 S_1}{p_2 S_2} < \beta < 1\right)$$

As the function implies, the model assumes that there is positive externality when *the type 2* investment succeed. The degree of such effect is in proportion to the number of the successful *type 2* investment project represented as $p_2 n_2$. Specifically, by the positive externality, successful *type 2* projects clean up the pollution emitted from *type 1* project partially. To specify, the term $n_1\beta(\frac{p_2 n_2}{p_1 n_1})g$

represents the total level of decreased pollution by *type 2* project's positive externality. β is assumed to be given as a parameter, meaning the technology level that *type 2 firm*'s project should contribute to decreasing the pollution level through the positive external effect. And it should be $0 < \beta < 1$, specifically $\left(\left(\frac{p_1}{p_2}\right)\frac{p_1 S_1}{p_2 S_2} < \beta < 1\right)$, implying that *type 2 firm's* project does not fully remove the pollution but only partially, as an external effect. Indeed, as β approaches to 1, it implies stronger positive externality.

How can these kind of positive externality be rationalized in reality? Specifically, there can be some technological spill-over effect that as green industry grows, these environmentally friendly technology of the industry would be easily transferred to the conventional industry. Or, if people get more concerned about the firm's environmental responsibility as green industry enlarges, the conventional industry firms would make some effort to reduce their pollutions.

Note that the degree of the negative externality or pollution that *type 1 firm's* project incur is assumed to be in proportional to the number of *type 1 firm* who get funded from a bank, whether it is successful or not. This kind of negative externality includes the pollution generated from the building process of the factory, so the degree of the negative externality should be proportional to n_1. The reason why we divided the number of successful *type 2 project,* $p_2 n_2$ by the number of successful *type 1 project,* $p_1 n_1$ is that the positive externality affects universally and equally and the degree of that effect is same for all *type 1 projects*.

However, under the private choice where all agents do not consider their externalities but only maximize their expected profit, neither firms nor a typical bank does not take account of these kinds of externality when they make decisions. So we can presume that the equilibrium without considering these effects would not be socially optimum and therefore the social return for investment is not maximized.

In the following sections of this paper, we will compare the difference between the private choice and the social planner's choice where the externalities are considered, which we call as '*socially optimum*'.

2.2 Private Choice : Funding for Investment Projects without Considering Pollution

The number of firms which succeed in funding from the bank will be determined in the market as a result of profit maximization problem of a bank. The lending rate R^* is a given parameter for a typical bank. The bank maximizes its expected return when allocating its financial capital to each type of firms, and only n_1 and n_2 are bank's decision variables.

$$(5)\quad \underset{n_1,n_2}{Max}\, E\pi_B = n_1[p_1(K-w)R_1 + (1-p_1)w] + n_2[p_2(K-w)R_2 + (1-p_2)w]$$

$$-\frac{1}{2}[n_1(K-w)]^2 - \frac{1}{2}[n_2(K-w)]^2 - n_1(K-w)R^* - n_2(K-w)R^* - cn_2$$

The first order conditions for profit maximization is as follows:

$$(6)\quad \frac{\partial E\pi_B}{\partial n_1} = p_1(K-w)R_1 + (1-p_1)w - n_1(K-w)^2 - (K-w)R^* = 0$$

$$(7)\quad \frac{\partial E\pi_B}{\partial n_2} = p_2(K-w)R_2 + (1-p_2)w - n_2(K-w)^2 - (K-w)R^* - c = 0$$

From (6) and (7) we can get the following:

$$(8) \quad n_1^* = \frac{p_1(K-w)R_1 + (1-p_1)w - (K-w)R^*}{(K-w)^2}$$

$$(9) \quad n_2^* = \frac{p_2(K-w)R_2 + (1-p_2)w - (K-w)R^* - c}{(K-w)^2}$$

The number of each type of projects determined above (8) and (9) are not an equilibrium quantity yet. We have to determine the equilibrium R_1 and R_2 in order to get the equilibrium n_1^* and n_2^*. In order to get the equilibrium, we need to consider each firm's profit function, equation (1) and (2). Note that the only decision for an investor is whether to undertake a project. Since both types of firms can earn wR^* for sure, the condition for firms to undertake their investment project is as follows:

Type 1 firm : (10) $p_1S_1 - p_1R_1(K-w) - (1-p_1)w \geq wR^*$

Type 2 firm : (11) $p_2S_2 - p_2R_2(K-w) - (1-p_2)w \geq wR^*$

As long as the inequality in (10) and (11) hold, investors should have an incentive to enter the market and undertake their project. As more firms enter the market, the borrowing rate will rise, until in (10) and (11) an equality hold, respectively.

Following terms are maximum borrowing rate that investors are willing to pay, which is also the equilibrium borrowing rate:

(12) $R_1^* = \dfrac{p_1S_1 + (1-p_1)w - wR^*}{p_1(K-w)}$ $\qquad \because p_1S_1 - p_1R_1(K-w) - (1-p_1)w = wR^*$

(13) $R_2^* = \dfrac{p_2S_2 + (1-p_2)w - wR^*}{p_2(K-w)}$ $\qquad \because p_2S_2 - p_2R_2(K-w) - (1-p_2)w = wR^*$

Assuming the lending rate charged by banks is equal to the borrowing rate above, the number of each firms that a bank decides to fund turns out as follows: (Substituting (12) and (13) into (8) and (9), respectively)

(14) $n_1^* = \dfrac{p_1S_1 - KR^*}{(K-w)^2}$

(15) $n_2^* = \dfrac{p_2S_2 - KR^* - c}{(K-w)^2}$

Comparing these two, we cannot determine which type of investment projects get funded more, since we have assumed $p_1S_1 < p_2S_2$ and because of the '*verification cost*', it is indeterminate whether $p_1S_1 - p_2S_2 < c$ or not. To which type of project a typical bank would fund more depends on a degree of the '*verification cost*'. This result implies that the reason why many *'green'* firms fail to borrow funds from the market is not because their return is lower than that of the conventional firms, but because of the high *'verification cost'* of the bank to distinguish these firms. Indeed, it is certain that the smaller the '*verification cost'* is, the more the number of the *type 2* project get funded from a bank.

Note that in the private choice equilibrium, all agents did not consider their externalities when they make decisions through profit maximization problem. Still, we can calculate the social pollution level in this case.

Recall the pollution level we defined as following:

$$(4)\quad G = n_1\,[g - \beta(\frac{p_2 n_2}{p_1 n_1})g] = n_1\,[1 - \beta(\frac{p_2 n_2}{p_1 n_1})]g \quad , \quad \left(\left(\frac{p_1}{p_2}\right)\frac{p_1 S_1}{p_2 S_2} < \beta < 1\right)$$

We can calculate G^*, the equilibrium pollution level when the externalities are not considered. Specifically, putting the private choice equilibrium n_1^* and n_2^* into (4) we can get:

$$(16)\quad G^* = \left[\frac{(p_1 S_1 - KR^*) - \beta(\frac{p_2}{p_1})(p_2 S_2 - KR^* - c)}{(K - w)^2}\right] g$$

Calculating the Gross Return for the investment,

$$(17)\quad n_1^* p_1 S_1 + n_2^* p_2 S_2 = \frac{(p_1 S_1)^2 + (p_2 S_2)^2 - KR^*(p_1 S_1 + p_2 S_2) - c(p_2 S_2)}{(K - w)^2}$$

However, we need to less the pollution level from the gross return to get the net return for the investment.

$$(18)\quad n_1^* p_1 S_1 + n_2^* p_2 S_2 - G^* = \frac{(p_1S_1)^2 + (p_2S_2)^2 - KR^*(p_1S_1 + p_2S_2) - c(p_2S_2)}{(K-w)^2}$$

$$- \left[\frac{(p_1S_1 - KR^*) - \beta(\frac{p_2}{p_1})(p_2S_2 - KR^* - c)}{(K-w)^2} \right] g$$

2.3 A Social Planner's Choice : Internalizing Pollution and Positive Externality

Different from the private choice problem where all agents including a bank do not consider the externalities into the decision making process, in this case, there exist the financial sector, or a social planner which internalize the externalities when they fund the investment projects.

In this case, note the each firm's profit maximization problem remain same. However, a typical bank which plays an important role in determining the number of investment projects, takes into account of the externalities when it makes a decision to fund each type of projects. A typical bank which internalizes pollution, or externalities into its expected profit maximizes the following:

(19) $$E\pi_S = n_1[p_1(K-w)R_1 + (1-p_1)w] + n_2[p_2(K-w)R_2 + (1-p_2)w]$$

$$-\frac{1}{2}[n_1(K-w)]^2 - \frac{1}{2}[n_2(K-w)]^2 - n_1(K-w)R^* - n_2(K-w)R^* - cn_2$$

$$-n_1\left[1-\beta(\frac{p_2 n_2}{p_1 n_1})\right]g$$

Note that in this case, the pollution is included as a negative profit for a bank when it maximizes their profit.

Since the choice variables for a bank are still n_1 and n_2,

(20) $$\underset{n_1,n_2}{Max}\, E\pi_S = n_1[p_1(K-w)R_1 + (1-p_1)w] + n_2[p_2(K-w)R_2 + (1-p_2)w]$$

$$-\frac{1}{2}[n_1(K-w)]^2 - \frac{1}{2}[n_2(K-w)]^2 - n_1(K-w)R^* - n_2(K-w)R^* - cn_2$$

$$-n_1[1-\beta(\frac{p_2 n_2}{p_1 n_1})]g$$

The first order conditions for (20) are as following:

(21) $$\frac{\partial E\pi_S}{\partial n_1} = p_1(K-w)R_1 + (1-p_1)w - n_1(K-w)^2 - (K-w)R^* - g = 0$$

(22) $$\frac{\partial E\pi_S}{\partial n_2} = p_2(K-w)R_2 + (1-p_2)w - n_2(K-w)^2 - (K-w)R^* - c + \beta(\frac{p_2}{p_1})g$$

$$= 0$$

The equilibrium number of each firms that succeed in borrowing from a bank are: (Note that we applied the same R_1 and R_2 as in the private choice, since each firm's expected profit do not change)

$$(23)\quad n_1^{**} = \frac{p_1 S_1 - KR^* - g}{(K-w)^2}$$

$$(24)\quad n_2^{**} = \frac{p_2 S_2 - KR^* + \beta(\frac{p_2}{p_1})g - c}{(K-w)^2}$$

Compared to the private choice equilibrium, the number of *type 1* investment project decreased in this case, in proportion to the level of the pollution level *g*. That is to say, a degree of negative externality imposed by *type 1* project has a negative relationship with the number of the socially optimum level of these projects. Moreover, from (24), we can observe that a bank funds more to *type 2 firm* compared to the case where the externalities are not considered. As the equilibrium result shows, the number of funded *type 2* project has a positive relationship with the probability that the *type 2* project succeed, and the clean-up technology level, or degree of a positive externality that *type 2* project incur.

Also, the pollution level under n_1^{**} and n_2^{**} is following:

$$(25)\quad G^{**} = \left[\frac{(p_1 S_1 - KR^* - g) - \beta\left(\frac{p_2}{p_1}\right)\left\{p_2 S_2 - KR^* - c + \beta\left(\frac{p_2}{p_1}\right)g\right\}}{(K-w)^2} \right] g$$

The gross return for total investment can be calculated as following:

(26) $n_1^{**} p_1 S_1 + n_2^{**} p_2 S_2$

$$= \frac{(p_1S_1)^2 + (p_2S_2)^2 - KR^*(p_1S_1 + p_2S_2) - c(p_2S_2) + \left[\beta\left(\frac{p_2}{p_1}\right)p_2S_2 - p_1S_1\right]g}{(K-w)^2}$$

The gross return in this case is higher than in the case of private choice, if $\beta\left(\frac{p_2}{p_1}\right) > \frac{p_1S_1}{p_2S_2}$ holds. Since β should be less than 1 but greater than 0, so the assumption that this condition to hold is not too forced one.

(26) > (17) $\leftrightarrow$ $n_1^{**} p_1S_1 + n_2^{**} p_2S_2 > n_1^{*} p_1S_1 + n_2^{*} p_2S_2$ if $\beta\left(\frac{p_2}{p_1}\right) > \frac{p_1S_1}{p_2S_2}$

Also, we know from the equilibrium result that the pollution level in private choice is higher.

(25) < (16) $\leftrightarrow$ $G^{**} < G^{*}$

Therefore, naturally the relationship (26) - (25) > (17) - (16) holds $\leftrightarrow$ $n_1^{**} p_1S_1 + n_2^{**} p_2S_2 - G^{**} > n_1^{*} p_1S_1 + n_2^{*} p_2S_2 - G^{*}$ if $\beta\left(\frac{p_2}{p_1}\right) > \frac{p_1S_1}{p_2S_2}$

The net return for the investment is higher than in the private choice where externalities are not considered when funding.

3 Equilibrium Analysis

3.1 Gross Return

As we have derived by previous discussions, we can compare the socially optimum with the private choice result. The gross return is higher in the socially optimum level than in the private choice where the externalities are not considered.

$$n_1^* p_1 S_1 + n_2^* p_2 S_2 = \frac{(p_1 S_1)^2 + (p_2 S_2)^2 - KR^*(p_1 S_1 + p_2 S_2) - c(p_2 S_2)}{(K-w)^2}$$

$$n_1^{**} p_1 S_1 + n_2^{**} p_2 S_2$$

$$= \frac{(p_1 S_1)^2 + (p_2 S_2)^2 - KR^*(p_1 S_1 + p_2 S_2) - c(p_2 S_2) + \left[\beta\left(\frac{p_2}{p_1}\right) p_2 S_2 - p_1 S_1\right] g}{(K-w)^2}$$

, $\beta\left(\frac{p_2}{p_1}\right) > \frac{p_1 S_1}{p_2 S_2}$ is assumed to be satisfied.

$$\therefore n_1^{**} p_1 S_1 + n_2^{**} p_2 S_2 > n_1^* p_1 S_1 + n_2^* p_2 S_2 \quad \text{if} \quad \beta\left(\frac{p_2}{p_1}\right) > \frac{p_1 S_1}{p_2 S_2}$$

3.2 Pollution

Pollution level is smaller in the socially optimum than in the private choice.

$$G^* = \left[\frac{(p_1 S_1 - KR^*) - \beta(\frac{p_2}{p_1})(p_2 S_2 - KR^* - c)}{(K-w)^2}\right] g$$

$$G^{**} = \left[\frac{(p_1S_1 - KR^* - g) - \beta\left(\frac{p_2}{p_1}\right)\left\{p_2S_2 - KR^* - c + \beta\left(\frac{p_2}{p_1}\right)g\right\}}{(K-w)^2} \right] g$$

$$\therefore G^{**} < G^*$$

3.3 Net Return

$$n_1^* p_1S_1 + n_2^* p_2S_2 - G^*$$
$$= \frac{(p_1S_1)^2 + (p_2S_2)^2 - KR^*(p_1S_1 + p_2S_2) - c(p_2S_2)}{(K-w)^2}$$
$$- \left[\frac{(p_1S_1 - KR^*) - \beta(\frac{p_2}{p_1})(p_2S_2 - KR^* - c)}{(K-w)^2} \right] g$$

$$\therefore n_1^{**} p_1S_1 + n_2^{**} p_2S_2 - G^{**}$$

$$= \frac{(p_1S_1)^2 + (p_2S_2)^2 - KR^*(p_1S_1 + p_2S_2) - c(p_2S_2) + \left[\beta\left(\frac{p_2}{p_1}\right)p_2S_2 - p_1S_1\right]g}{(K-w)^2}$$

$$- \left[\frac{(p_1S_1 - KR^* - g) - \beta\left(\frac{p_2}{p_1}\right)\left\{p_2S_2 - KR^* - c + \beta\left(\frac{p_2}{p_1}\right)g\right\}}{(K-w)^2} \right] g$$

$$\therefore n_1^{**} p_1S_1 + n_2^{**} p_2S_2 - G^{**} > n_1^* p_1S_1 + n_2^* p_2S_2 - G^* \quad \text{if } \beta\left(\frac{p_2}{p_1}\right) > \frac{p_1S_1}{p_2S_2}$$

4 Implications

By comparing the private choice with social planner's choice, we were able to derive the result that the gross return as well as the net output of the investment is higher and the pollution level is lower in the case when the financial sector includes the externalities of investments which it finances into their profit function.

Under the private choice where all agents do not consider their externalities, the expected social rate of return is lower and the level of pollution is higher than in the socially optimum choice where banks consider external effects of the projects they are financing when they allocate the funds. As we have shown, in the private choice, under-investment for environmentally friendly projects and over-investment for non-environmentally friendly projects occur.

There exist several policy measures we can think of to correct these under-investment and over-investment problems. Basically the key issue is how make private agent internalize the externalities. First is to give incentives to each type of firms, affecting firms' return depending on the type of their investment. Providing subsidy on *type 2 firms'* return on when their investment project succeed and imposing tax on firm's return on *type 1 firms'* return when their investment project succeed would be optimal policy to achieve the socially optimal level. We will determine the optimal degree of subsidy or tax rate that achieve socially optimum level of investment projects mathematically.

Another measure we can think of is to give incentive to the bank side; that is, to make the cost of mobilizing funds different when banks finance to each type of investment projects. Note that we have assumed that banks mobilize the necessary funds by paying R^* on $(n_1 + n_2)(K - w)$. However, by imposing penalty when banks mobilize the necessary funds to finance the *type 1* projects and letting banks mobilize with lower cost than R^* when they fund for the *type 2* projects simultaneously, the socially optimum level can be achieved. Then we can determine the optimal level of penalty rate and subsidy rate that correct the inefficiencies under the private choice.

Generally, the procedure of imposing taxes and giving out subsidies generate additional costs and if these kind of costs are higher than the benefits from the policies, then it would be more preferable not to apply the policies. However, in our analysis, by implicitly assuming that such costs are small enough, we did not include the factor in the analysis.

4.1 Incentive to the Firm's side; Imposing Taxes on Returns on the Investment

In this case, banks maximize the following profit function, which is same as the private choice. However, the return of the investment projects are affected depending on their type ; government impose taxes on the *type 1* project's return and give subsidy to *type 2* project's return. Banks' expected profit function remains same as follows:

$$(3)\quad E\pi_B = n_1[p_1(K-w)R_1 + (1-p_1)w] + n_2[p_2(K-w)R_2 + (1-p_2)w]$$
$$-\frac{1}{2}[n_1(K-w)]^2 - \frac{1}{2}[n_2(K-w)]^2 - n_1(K-w)R^* - n_2(K-w)R^* - cn_2$$

Accordingly, the first order conditions are same as previously.

(6) $$\frac{\partial E\pi_B}{\partial n_1} = p_1(K-w)R_1 + (1-p_1)w - n_1(K-w)^2 - (K-w)R^* = 0$$

(7) $$\frac{\partial E\pi_B}{\partial n_2} = p_2(K-w)R_2 + (1-p_2)w - n_2(K-w)^2 - (K-w)R^* - c = 0$$

And the equilibrium number of investment projects that banks finance are:

(8) $$n_1 = \frac{p_1(K-w)R_1 + (1-p_1)w - (K-w)R^*}{(K-w)^2}$$

(9) $$n_2 = \frac{p_2(K-w)R_2 + (1-p_2)w - (K-w)R^* - c}{(K-w)^2}$$

Note that since each firm's profit functions are changed, the equilibrium level of R_1 and R_2 would be determined at different level. As discussed before, each firm would be willing to participate in the investment only when their expected profit exceed the opportunity cost, wR^*.

Following are each firm's expected returns after this policy:

Type 1 firm : (27) $E\pi_{f1'} = p_1 S_1(1-\tau) - p_1 R_1(K-w) - (1-p_1)w \geq wR^*$

Type 2 firm : (28) $E\pi_{f2'} = p_2 S_2(1+\nu) - p_2 R_2(K-w) - (1-p_2)w \geq wR^*$

The equilibrium R_1 and R_2 will be determined at the level where these two equalities hold.

(29) $R_1^{\ R} = \dfrac{p_1S_1(1-\tau)+(1-p_1)w-wR^*}{p_1(K-w)}$

$\because\ p_1S_1(1-\tau)-p_1R_1(K-w)-(1-p_1)w = wR^*$

(30) $R_2^{\ R} = \dfrac{p_2S_2(1+\nu)+(1-p_2)w-wR^*}{p_2(K-w)}$

$\because\ p_2S_2(1+\nu)-p_2R_2(K-w)-(1-p_2)w = wR^*$

Putting these two into (8) and (9), the equilibrium number of each projects, denoted by $n_1^{\ R}$ and $n_2^{\ R}$ are determined as follows:

(31) $n_1^{\ R} = \dfrac{p_1S_1(1-\tau)-KR^*}{(K-w)^2}$ (32) $n_2^{\ R} = \dfrac{p_2S_2(1+\nu)-KR^*-c}{(K-w)^2}$

Recall the socially optimum number of funded investment projects that government aims to achieve by this policy.

(23) $n_1^{\ **} = \dfrac{p_1S_1-KR^*-g}{(K-w)^2}$ (24) $n_2^{\ **} = \dfrac{p_2S_2-KR^*+\beta(\frac{p_2}{p_1})g-c}{(K-w)^2}$

To equalize (31) and (23), the optimal level of τ and ν are determined as

(33) $\tau^* = \dfrac{g}{p_1S_1}$ (34) $\nu^* = \dfrac{\beta}{p_2S_2}$

4.2 Incentive to the Bank's side; Imposing Taxes on the Cost of Mobilizing Funds

As we have mentioned above, another way of achieving the socially optimum level of financed investment projects is to make banks to face with different cost of mobilizing capital depending on the type of project they are financing. Now we assume that for banks, the cost to mobilize $n_1(K-w)$ amount of financial capital for *type 1 firm* becomes $n_1(K-w)(1+\mu)R^*$ as the government charges penalty, in the form of proportional tax to the price of capital when banks finance the *type 1* projects. On the other hand, the government subsidizes the cost when banks mobilize capital to finance the environment-friendly investment projects. The term $n_2(K-w)(1-\varphi)R^*$ represents the bank's effective financing cost to get $n_2(K-w)$ amount of capital to fund the *type 2* projects. As it shows, under this kind of policy, the government subsidize the cost of mobilizing capital that banks need in order to finance the *type 2* project whereas it puts some penalty when banks finance the *type 1* project. The revised expected profit they maximize is as follows:

$$(35) \quad E\pi_F = n_1[p_1(K-w)R_1 + (1-p_1)w] + n_2[p_2(K-w)R_2 + (1-p_2)w]$$

$$-\frac{1}{2}[n_1(K-w)]^2 - \frac{1}{2}[n_2(K-w)]^2 - n_1(K-w)(1+\mu)R^* - n_2(K-w)(1-\varphi)R^* - cn_2$$

$$, \ (0<\mu<1 \ , \ 0<\varphi<1)$$

$(1+\mu)R^*$ and $(1-\varphi)R^*$ becomes the effective interest rate that banks face when they mobilize capital for the *type 1* project and the *type 2* project, respectively.

The first order condition for (35) is as follows:

(36) $$\frac{\partial E\pi_F}{\partial n_1} = p_1(K-w)R_1 + (1-p_1)w - n_1(K-w)^2 - (K-w)(1+\mu)R^* = 0$$

(37) $$\frac{\partial E\pi_F}{\partial n_2} = p_2(K-w)R_2 + (1-p_2)w - n_2(K-w)^2 - (K-w)(1-\varphi)R^* - c = 0$$

We obtain the number of *type 1* and the *type 2* projects which succeed in getting financed from banks as shown below.

(37) $$n_1^F = \frac{p_1(K-w)R_1 + (1-p_1)w - (K-w)(1+\mu)R^*}{(K-w)^2}$$

(38) $$n_2^F = \frac{p_2(K-w)R_2 + (1-p_2)w - (K-w)(1-\varphi)R^* - c}{(K-w)^2}$$

To get the equilibrium number of each investment project, we should determine the equilibrium R_1 and R_2. Recall the following equilibrium interest rates for each firm when banks could mobilize funds with same interest rate R^* regardless of the type of project they are financing.

(12) $$R_1^* = \frac{p_1S_1 + (1-p_1)w - wR^*}{p_1(K-w)} \qquad \because p_1S_1 - p_1R_1(K-w) - (1-p_1)w = wR^*$$

(13) $$R_2^* = \frac{p_2S_2 + (1-p_2)w - wR^*}{p_2(K-w)} \qquad \because p_2S_2 - p_2R_2(K-w) - (1-p_2)w = wR^*$$

However, since banks mobilize funds with different interest rate depending on the type of project they are financing, each type of firms' opportunity cost of borrowing for investment also changes. The equilibrium interest rate that each firm pays to the bank are assumed to be determined at the level where the opportunity cost and the firm's expected profit get equalized. Therefore the change in bank's cost of mobilizing funds would be passed over partially to each firm's equilibrium interest rate. As explained previously, each type of firms would have incentive to involve in investing when the expected profit when investing exceed the opportunity cost, $wR^*(1+\mu)$ and $wR^*(1-\varphi)$ respectively for the *type 1 firm* and the *type 2 firm*. And the equilibrium R_1 and R_2 will be determined at the level where these two equalities are satisfied.

Each firm's expected profit and their opportunity cost are as follows:

(39) $p_1 S_1 - p_1 R_1 (K-w) - (1-p_1)w \geq wR^*(1+\mu)$

(40) $p_2 S_2 - p_2 R_2 (K-w) - (1-p_2)w \geq wR^*(1-\varphi)$

Following are the equilibrium interest rates when equalities hold in (39) and (40).

(41) $R_1^F = \dfrac{p_1 S_1 - (1-p_1)w - wR^*(1+\mu)}{p_1(K-w)}$

(42) $R_2^F = \dfrac{p_2 S_2 - (1-p_2)w - wR^*(1-\varphi)}{p_2(K-w)}$

Substituting (41) and (42) into (37) and (38), we get the equilibrium number of projects which succeed in financing.

(39) $n_1^F = \dfrac{p_1 S_1 - K\mu R^*}{(K-w)^2}$ (40) $n_2^F = \dfrac{p_2 S_2 - KR^* + K\varphi R^* - c}{(K-w)^2}$

To yield the optimal level of two policy variables μ *and* φ to achieve the socially optimum level of each funded investment projects, we have to compare (39) and (40) with the socially optimum number of each firms. Recall the socially optimum level of projects. Recall the socially optimum level,

(23) $$n_1^{**} = \frac{p_1 S_1 - KR^* - g}{(K-w)^2}$$ (24) $$n_2^{**} = \frac{p_2 S_2 - KR^* + \beta(\frac{p_2}{p_1})g - c}{(K-w)^2}$$

To determine the policy variable which yield the same level as socially optimum, $K\mu R^*$ should be equal to g and $K\varphi R^*$ should be equal to $\beta(\frac{p_2}{p_1})g$.

Consequently, the optimum level of μ and φ are as follows:

(41) $$\mu^* = \frac{g}{KR^*}$$ (42) $$\varphi^* = \frac{\beta\left(\frac{p_2}{p_1}\right)g}{KR^*}$$

5 Conclusion and Further Discussions

This paper analyzed theoretically why under-investment for '*green*' projects and over-investment project for conventional projects occur. We focused on the *asymmetric information problem* between *'green'* firms and the financial sector as well as the externalities that each investment projects incur as the key factors. Since banks as private agent do not consider the externalities of the investment projects, they fail to allocate funds at the socially optimum level.

To summarize, under the private choice where all agents do not consider their externalities, the expected social rate of return is lower and the level of pollution is higher than in the socially optimum choice where each bank considers external effects when they decide the number of each type of project they would fund. In the private choice, under-investment for environmentally friendly projects and over-investment for non-environmentally friendly projects occur. In order to achieve the socially optimum level of output, net return and the level of the pollution, methods to correct the number of projects getting financed should be considered.

We proposed policy methods of internalizing externalities to correct these under-investment and over-investment problems. By doing these policies, banks become economically motivated to allocate more funds to the '*green'* industry, and the social return as well as the pollution get improved thus contributing to '*Green Growth'*. First is to give incentive to firms on their returns, depending on the type of their investment. Providing subsidy on the *type 2 firms'* return when their investment project succeed and imposing tax on firm's return on *type 1 firms'* return when their investment project succeed was one of the optimal policies to achieve the socially optimal level. We derived the optimal degree of subsidy or tax rate that helps to achieve socially optimum level of investment projects.

Another way of letting the private choice yield the socially optimum level is to make banks to face with different cost of mobilizing capital depending on the type of project they are financing. Also for this case, we were able to derive the optimal level of the policy variable.

Besides methods of inducing private agents to internalize like we have discussed previously, we can further consider the policy option of alleviating *asymmetric information problem* between banks and *'green'* firms. The idea is to decreasing c in the model, which represents the '*verification cost'* for banks to determine information regarding *'green'* investment projects. If screening services are provided and the cost of using the service is cheaper than the '*verification cost',* then banks would have incentive to use the service and the *asymmetric information problem* can be alleviated more efficiently. Actually this kind of methods are in practice in '*Green Finance'* market. In Korea for example, '*Green Certificate System'* has been in practice since 2010 (Koo, 2010). This certificate system allows banks which lend out to the new firms with risky '*green*' technology be provided with the information to screen these firms. On the firm side, small firms which find it hard to borrow through the conventional corporate finance, would have economic incentives to pay some cost to get this guarantee from the '*Green Certificate'* on their technologies. Alleviating the *asymmetric information problem* by these procedure, this practice decreases the verification cost in our model thus allowing the number of '*green'* investment projects to increase.

It is true that being a simple model, there should be many limitations for explaining *'Green Finance'* in our model. More fundamentally, some would not agree with the idea of explaining '*Green Finance'* mainly through two factors, 'externality' and '*asymmetric information problem'*. However, as I mentioned in the very start of the paper, the purpose of this paper is to build an economic model which explains the phenomenon that many firms with new investment projects such as *'green'* technology fail to be financed from the financial market. So the simplifications and imposing somewhat strict assumptions were inevitable. Nonetheless, we have successfully shown the result clearly that the total output, net output are higher and pollution level is lower in the case when considering externalities and we also derived the optimal policy measures. Being a theoretical model, our paper did not put much effort to the practical issues involved with *'Green Finance'*. Nonetheless, the implications derived by the simple model may provide some fundamental guideline for implementing the practical *'Green Finance'* policies in the future.

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국문 초록

녹색금융 분석 :
외부성 존재 시 금융자본 배분 문제에 관하여

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본 논문은 현실에서 환경에 긍정적 외부효과가 큰 녹색산업과 관련된 프로젝트에 투자하려는 기업들이 자본시장에서 자금을 조달하기 어려운 현상을 경제학적 모형을 통하여 분석하였다. 이를 통하여 환경보호와 경제성장을 동시에 달성하려는 '녹색성장'에 있어 금융부문의 역할 및 금융정책의 중요성을 강조하였다.

먼저, 위험성이 크지만 성공 시 수익이 크고 긍정적 외부효과가 있는 녹색산업과, 위험성이 작지만 성공 시 수익이 상대적으로 작고 환경에 부정적인 외부효과가 있는 전통적 산업 두 가지 산업에 금융자본을 배분하는 은행의 선택문제를 중심으로 분석하였다. 현실에서 녹색산업에 속한 기업들의 자금조달이 어려운 이유를 외부성의 존재와 정보비대칭성의 문제 두 가지로 보고, 이 두 요소를 모형에 반영하여 기업들에게 금융자본을 배분할 때 사적 이익을 극대화하는 경제주체와 오염물질 및 긍정적인 외부효과를 고려하는 사회 정책 결정자(Social Planner)의 선택의 차이를 살펴보았다. 그 결과, 금융자본을 각 기업에 배분하는 금융기관이 각 기업의 프로젝트가 지니는 외부효과를 고려하여 기업들에게 대출해줄 때 사회적으로 공해 수준이 감소하며, 동

시에 더 큰 사회적 투자 수익을 얻을 수 있다는 결론을 보였다.

더 나아가, 사적 선택의 결과를 사회적 최적 수준으로 만들기 위해 외부효과를 내재화 시키기 위한 적절한 금융정책을 모형을 통하여 도출하였다. 녹색산업에 해당되는 기업의 투자수익에 적정 보조금을 주는 동시에 非녹색산업에 해당되는 기업의 투자수익에 대해서는 적정 조세를 부과하여 사회적 최적수준과 동일한 균형을 달성할 수 있다. 또한 은행이 각 산업에 금융자본을 배분하는데 있어, 녹색산업에 해당하는 기업에 조달하는 자본에 대해서는 시장이자율보다 더 낮은 수준을 허용하고 동시에 비 녹색산업 기업에 조달하는 자본에 대해서는 시장이자율 보다 더 높은 수준을 허용함으로써 사회적 최적수준과 동일한 균형을 달성할 수 있다.

외부효과를 내재화시키는 금융정책 외에도, 금융기관과 녹색산업 간 존재하는 정보비대칭성을 완화하는 정책 또한 가능한데, 본 논문에서 이는 외부효과를 내재화 시키는 금융정책에 비해 사회적 최적상태를 달성하는데 있어서 부분적인 효과를 지닌다.

이러한 경제학적인 모형분석을 통하여 본 논문은 '녹색성장'을 달성하는데 금융기관의 자원배분역할의 중요성을 보여주며, 동시에 적절한 금융정책의 방향, 구체적으로 각 정책변수의 적정수준을 경제학적 모형을 통하여 도출함으로써 향후 녹색금융이 나아갈 방향을 제시하였다.

주 요 어 : 녹색금융, 녹색성장, 외부성, 환경오염, 시장실패

학 번 : 2011-23172